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Behavioral Economics of Drug Self-administration: an Introduction	

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13. ABSTRACT (Maximum 200 words)

Behavioral economics provides a set of concepts for the analysis of factors that control the allocation of behavioral resources among available reinforcers. Terms from micro-economics describe new phenomena previously ignored within the traditional context of behavior analysis. This article reviews these concepts as an introduction to the three papers that follow. The primary dependent measure within the behavioral economic framework is the level of consumption of available commodities as determined by the level and distribution of instrumental responding. The demand curve provides a quantitative metric for analyzing consumption under the constraint of unit price. When the reinforcer is a drug, the demand curve can be a useful tool for analyzing the level of motivation to consume the drug, its abuse liability, and for evaluating interventions, such as alternative reinforcers or medications, to reduce the motivation to consume the drug and instrumental responding to obtain it. Behavioral economics also provides a framework for formulating, testing, and refining drug abuse policy through a series of empirical steps that maximize effectiveness and minimize undesirable social consequences.

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Behavioral economic concepts

One of the most important contributions of behavioral economics has been to redirect our attention to total daily consumption as a primary dependent measure of behavior. In this context, responding is regarded as a secondary dependent variable that is important because it is instrumental in controlling consumption. Consideration of consumption as a primary factor required a major methodological shift. In most behavioral experiments the practice has been to control 'drive' by imposing some deprivation schedule. Animals reinforced by food are held to 80% of free-feeding weight by limiting daily consumption and supplementing the amount of food earned in the test session with just enough food to hold body weight within a restricted range. This strategy was designed to hold 'drive' constant and eliminate a confounding factor. Inadvertently, the practice also eliminated one of the major factors controlling behavior in the natural environment, defense of consumption. Under conditions of controlled drive, responding is not instrumental in determining daily consumption. This strategy of controlling deprivation or consumption independent of behavioral changes is what I have termed an 'open economy' (Hursh, 1980, 1984). In more recent experiments, control of deprivation has been eliminated and subjects have been allowed to control their own level of consumption, what I have termed a 'closed economy'. The finding is that radically different sorts of behavioral adjustments occur in these two types of economies, especially when the reinforcer is a necessary commodity like food or water (see Hursh, 1978, 1984; Hursh and Natelson, 1981; Lucas, 1981; Collier, 1983; Collier et al., 1986; Hursh et al., 1988; Raslear et al., 1988; Hursh et al., 1989; Bauman, 1991). Fortunately, for those interested in drugs as reinforcers, most experiments involving drug self-administration have arranged a closed economy for the drug reinforcer; all drug administrations are response-dependent (Johanson, 1978). It is important, however, when comparing this behavior to behavior reinforced by another reinforcer, such as food, that a closed economy be arranged for that reinforcer as well. The behavioral difference between open and closed economies is best understood in terms of demand for the reinforcer, discussed next.

Demand curve analysis

The relationship between reinforcer cost and reinforcer consumption is termed a 'demand curve'. As the cost of a commodity increases, consumption decreases, illustrated in Fig 1. The rate of decrease in consumption (sensitivity to price) relative to the initial level of consumption, is called 'elasticity of demand'. When consumption declines slowly with proportionately large increases in price, we define that as 'inelastic demand'. For this to occur, total responding must increase with increasing cost. For example, when the price of gasoline increased threefold during the 1970s from 33 cents a gallon to over one dollar a gallon, consumption decreased by only 10%. This was an example of inelastic demand and the result was that a larger share of household budgets were allocated to gasoline than were before.

Not all demand curves are inelastic; consumption of saccharin sweetened water by a monkey with an alternative source of water is elastic (Fig 2). In the figure, the price of each commodi-
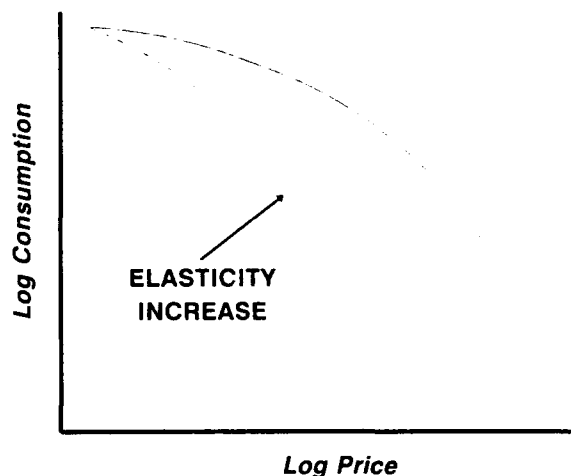

Fig. 1. Demand curve showing the usual shape and an increase in sensitivity to price termed an elasticity increase.
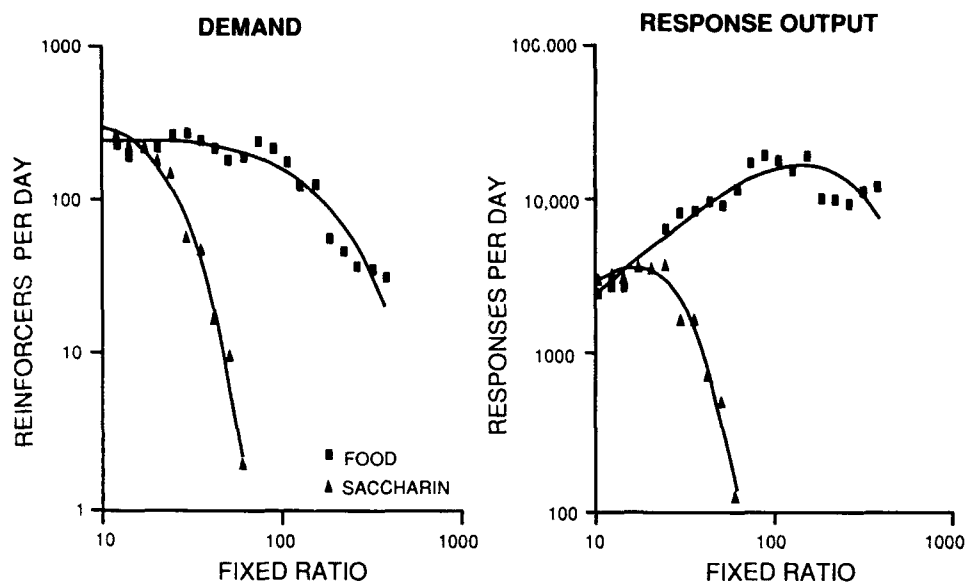
DEMAND

RESPONSE OUTPUT

Fig. 2. Left panel: two demand curves by a rhesus monkey working for either food (squares) or saccharin sweetened water (triangles). The functions show the total number of reinforcers earned each day under a series of fixed-ratio (FR) schedules that ranged from FR 10–372. Right panel: daily output of responding that accompanied the levels of consumption shown in the left panel.

ty (food or saccharin) was gradually increased from ten responses per reinforcer to over 372 responses per reinforcer in a closed economy. Consumption declined slowly for food but declined steeply for saccharin. As a corollary, total responding for food increased over a broad range while responding for saccharin generally decreased over the same range. The distinction between elastic and inelastic reinforcers defines a continuum. Consumption of all reinforcers becomes elastic if the price is elevated sufficiently; the difference between reinforcers can be specified in terms of the point of transition between inelastic and elastic demand (P_{max}) and coincides with the peak of the response rate functions shown in the right panel of Fig. 2. If that transition occurs at relatively low prices, then demand for that reinforcer is generally more elastic than demand for a reinforcer that sustains response increases over a broad range of prices. In the article that follows by Marilyn Carroll, this approach was used to demonstrate that the addition of a saccharin reinforcer concurrent with a PCP reinforcer had the effect of

increasing the elasticity of demand for PCP, increasing the slope of the demand curve and decreasing the price at which responding reached its peak. In general, demand curves for drug reinforcers conform to the same non-linear, decreasing function typified by those in Fig 2 and responding is an inverted U-shaped function of price (see below for details; also see review by Bickel et al., 1990). As discussed by Bickel et al., in their article, elasticity of demand may be a useful basic metric for comparing different drug reinforcers for abuse liability and for assessing the potency of interventions to reduce demand for drugs as reinforcers.

Elasticity of demand

Elasticity of demand is not an inherent property of the reinforcer. For example, one of the primary differences between open and closed economies is elasticity of demand. While demand for food is inelastic in a closed economy (see Fig 2) where the subject controls its own intake and no supplemental food is provided, demand for food in an open economy can be quite
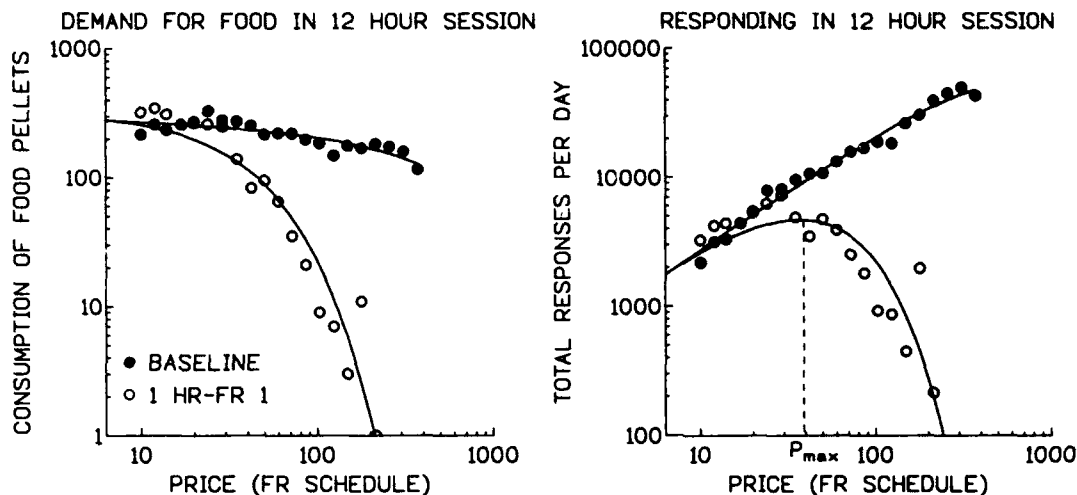
Fig. 3. Left panel: two demand curves by a rhesus monkey for food during a 12 h work period, either with no other source of food (●) or with a 1-h period of FR 1 food reinforcement immediately following the work period. (O) Consumption is shown as a function of the FR schedule that ranged from FR 10–372. Right panel: the total number of responses emitted per day that produced the levels of food consumption during the work period shown in the left panel.

elastic. To illustrate this point, we provided a monkey access to low cost food requiring only one response per pellet (fixed ratio 1 or FR 1) for 20 min after a 12 h work period for food at higher prices. The price of food in the work period was increased to assess demand (Fig 3). The subject could work for food in the work period at the prevailing price or wait and obtain food at a lower price later, analogous to obtaining low cost food in the home cage within an open economy. Compared to demand for food when no low cost food was available, demand when an alternative source was available was much more elastic and responding reached a peak at a much lower price, indicated as P_{max}. Comparing Fig. 3 with Fig. 2, one can conclude that the addition of a substitute food source functioned to convert food in the work period into an elastic commodity, very similar to the non-nutritive saccharin solution shown in Fig. 2 and discussed above. In general, elastic demand is typical for all reinforcers studied in an open economy.

In the context of drug abuse therapy, an alternative drug reinforcer such as methadone may be used as a medical intervention designed to reduce demand or increase elasticity of demand for the drug of abuse. Behavioral economics provides an approach to evaluation of the behavioral efficacy of this sort of drug therapy. In a manner parallel to that shown in Fig. 3 and discussed in the previous paragraph, the subject would be required to work for the target drug during 'work periods'; varying amounts of the therapy drug would be given at other times, either independently or as a consequence of an operant response, during a 'medication period'. The efficacy of different therapies would be measured in terms of their effects on the elasticity of demand for the target drug measured during the work periods. As Bickel et al. describe below, quantitative tools are available for specifying these changes in terms of the parameters of a demand equation (Hursh et al., 1988; Hursh et al., 1989; Hursh, 1991).

Measuring elasticity of demand

In order to use elasticity of demand as a basic yardstick for evaluating 'motivation' for drug reinforcers, we must precisely specify the conditions for measuring demand. This includes clear definitions of the two primary variables, consumption and price. I have proposed that consumption be measured in terms of total daily

intake, which, for drug reinforcers, becomes weight of drug per day adjusted for the weight of the subject (mg/kg/day). Many prior studies have measured consumption as 'injections per hour' or some other measure of reinforcement rate. This measure obscures the assessment of consumption because total drug intake is the product of 'number of reinforcers (infusions)' and 'dose (mg/kg/infusion)'. The behavioral economic focus is on total consumption as a controlling factor and requires an appropriate measure of consumption that considers dose as a constituent factor.

I have also proposed that price be specified as the ratio of response cost to reinforcer gain, termed 'unit price' (Hursh, 1984; Hursh et al., 1988; Bickel et al., 1990; Bickel et al., 1991). The most important implication of unit price for the understanding of drug reinforcement is that it specifies that consumption is similarly controlled by increases in cost and decreases in dose. In other words, responses per reinforcer and dose per reinforcer can both be thought of as cost factors and have a monotonic relationship to consumption. A stricter interpretation of unit price is implied by the analysis by Bickel et al., and tested by Nader et al., below. In those articles, the constituents of unit price, response cost and dose, are assumed to have scaler equivalence as well. In other words, a doubling of response cost is precisely equal to a halving of dose. Both Bickel et al., for the low dose case, and Nader et al., in their experiment with cocaine indicate that scalar equivalence may not be true in all cases. Nevertheless, both articles support the weaker notion of unit price, that increasing response cost and decreasing dose both function similarly to decrease consumption. As we extend research in this area we will define the domain of scalar equivalence of these two factors and, perhaps, define rescaling factors that are required for specific drugs or situations. The problem that confronts us with unit price is not so different from that encountered when attempting to specify the combined effects of reinforcer delay and reinforcer frequency on the strength of responding. Decreasing reinforcer frequency and amount function similarly to

decrease response strength, but, generally, frequency is more powerful than amount in controlling choice between two alternatives (Schneider, 1973; Todorov, 1973; see Davison and McCarthy, 1988, for review).

Reinforcer interactions

Behavioral economics specifies a range of interactions that may occur among different reinforcers available to the subject. For convenience, we label these interactions as 'substitution', 'complementarity', and 'independence'. Substitution and complementarity are illustrated in Fig 4. In each case, the term refers to the functional relationship between consumption of one reinforcer (commodity) and the price of another. If consumption of one reinforcer (commodity B, Fig. 4) increases with increases in price of another (commodity A), then commodity B is said to be a substitute for commodity A. For example, consumption of sugar pellets by a rat will increase as we increase the price of rat chow; consumption of rat chow is driven down by its price and consumption of sucrose in-
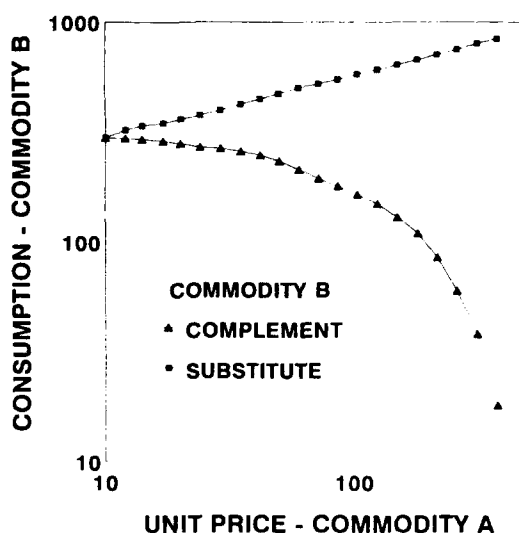

Fig. 4. Diagram of two forms of reinforcer interactions, complementarity (triangles) and substitution (squares), that describe changes in consumption of commodity B that may result from changes in the price of commodity A.

creases to serve as a substitute. If consumption of a reinforcer decreases with increases in the price of another, then the first is said to complement the other. For example, consumption of water will decrease as the price of dry food chow is increased; with declining food consumption less water is consumed as a complement. In certain cases, the price of one reinforcer will have no consistent effect on the consumption of another; in this case, the two are considered independent. The study described by Carroll illustrates how saccharin serves as a functional substitute for PCP consumption and also serves to increase elasticity of demand for PCP in comparison to demand for PCP alone. While not totally eliminating PCP self-administration, this study provides a model for how to evaluate any competing reinforcer as a 'therapy' for drug use.

The evidence from studies with food indicates that demand for a commodity is most sensitive to modification by a substitute at relatively high prices (Hursh et al., 1989). This is confirmed by the results shown by Carroll with PCP and saccharin. The largest differences in consumption and responding occurred at unit prices in excess of 160. This suggests that demand-side interventions need to be combined with supply-side restrictions that insure that the market price remains relatively high. These kinds of laboratory findings have direct implications for a balanced national drug abuse policy.

Behavioral economics of acquisition and extinction of responding

The studies by Carroll break new ground in the area of behavioral economics. Most prior studies have concentrated on the modulation of stable levels of previously established performances. In this study, Carroll extends the analysis to economic factors that may moderate the acquisition and extinction of performances, in these studies maintained by drug reinforcement. It is evident that the availability of a concurrent substitute interferes with the rate of acquisition of cocaine self-administration. In addition, withdrawal from PCP self-administration was

shown to reduce demand for food and this reduction in demand was greatest when food reinforcement was maintained within an 'open economy' which would be expected to generate greater elasticity of demand for food (see Fig. 3).
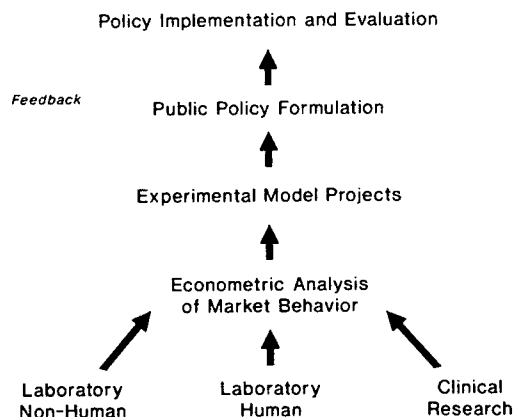
Behavioral economics and the problem of drug abuse

Behavioral economic approaches to the problem of drug abuse can make contributions in several important domains. First, as pointed out by Bickel et al., the analysis of demand curves for drug reinforcers can serve as a convenient metric for comparing the 'motivation' to procure and consume the drug. Quantitative methods are available which could provide a standardized system for evaluating new pharmaceuticals for abuse liability (Hursh et al., 1988; Hursh et al., 1989; Hursh, 1991).

Secondly, behavioral economic methods may be used to explore the interaction between drugs as reinforcers, especially between illicit drugs and those proposed as therapies. I would suggest that an acceptable therapy drug must have three essential characteristics. First, the therapy must be behaviorally efficacious in substantially reducing demand for the illicit drug. Behavioral efficacy could be evaluated as described above in terms of the effects of the therapy drug administered during medication periods on the elasticity of demand for the illicit drug during work periods. Second, the therapy drug must be behaviorally safe. The behavioral economic evaluation will indicate the dose and schedule of medication necessary to reduce drug demand. Behavioral economic and performance assessment methods can then be used to evaluate the behavioral effects of that therapy dose on cognitive and physical performance, as well as on general motivation for other activities. An acceptable therapy should have minimal effects on performance and general motivation. Third, to insure compliance with the medication regimen, the therapy drug must be shown to be non-aversive or even mildly reinforcing. While many techniques are available for evaluating the

aversive properties of a stimulus, an economical method would evaluate the properties of the medication within the context of efficacy testing. As described above, the medication would be given during designated 'medication periods'; rather than dispensing the medication automatically, the drug could be offered to the subject according to a response-dependent schedule. If the beneficial properties of the drug support self-administration of the medication during medication periods, then we can be reasonably assured that the medication is not aversive and that compliance with a clinical medication schedule would occur. Therefore, by applying behavioral techniques, a program of testing would insure that three evaluation criteria are satisfied and that the proposed medication would be effective, safe, and practical.

Finally, the behavioral economic model offers a framework for formulating a systematic, empirically based national policy for the control of drug abuse. This approach has been explained in Hursh (1991) and is summarized in Fig 5. Laboratory data are needed on any proposed medication or policy strategy. It is possible with behavioral economic methods to model with human subjects or non-human primates, the essential economic features of the proposed policy.

An artificial environment can be established using tokens to compensate for work and to serve as money to purchase alternative commodities including the illicit drug. Any policy can then be modeled in terms of the simulated wage rates and consumption prices. The probable outcomes of the policy can be tested in terms of its effects on illicit drug consumption, work to obtain the illicit drug, sensitivity to therapy interventions, and sensitivity to supply-side restrictions.

The experimental results can then be combined with knowledge about the actual demand elasticities of the illicit market place to more precisely define the policy parameters. This refined policy proposal can then be tested in model projects to insure that unanticipated dynamics of the market do not overwhelm the expected effects of the policy. Based on further refinements from model projects, a rational national policy can be formulated that has minimal risk, maximal chances of success, and long-term benefit to society.

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Policy Implementation and Evaluation

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Feedback   Public Policy Formulation

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Experimental Model Projects

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Econometric Analysis
of Market Behavior

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Laboratory   Laboratory   Clinical
Non-Human   Human   Research

Fig. 5. Diagram of the systematic application of behavioral economic methods for the formulation and refinement of drug abuse policy.

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